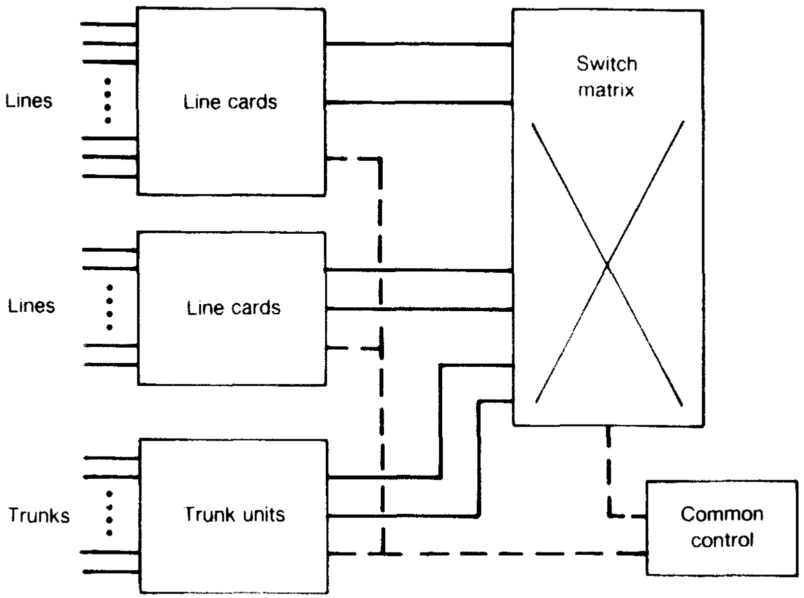


Fig 6—Block diagram of digital switch

interoffice trunks, to other switches in the larger network.[1] The *switch matrix* provides a continuous path connecting two subscriber lines (or a line and an interoffice trunk) for the duration of a call. The *common control* equipment is a digital computer that supervises the other switch components, causes switching connections to be established and removed, provides special subscriber services, and does accounting and maintenance.

In digital switches the major subcomponents of the peripheral equipment can be added in modular form, allowing capacity to be adjusted in anticipation of changes in demand for lines and trunks. The capacity of the switch matrix can also be expanded, but only in larger discrete units. And, depending on the architecture of the particular switch, the central control module may have a totally fixed capacity or be expandable in relatively large lumps.

[1]Other sources of network traffic also connect to the switch through peripheral units. These sources include private branch exchanges (PBXs), which provide switching among telephones in a business location, and remote switching units, which provide switching services to smaller concentrations of subscribers some miles from the central office.

Call Processing

Processing a local call involves the following events:

1. A call arrives at the switch on an analog subscriber line. Peripheral equipment (a line card) provides a variety of essential functions. The equipment supplies battery voltage to the subscriber's telephone and detects the off-hook request for service and dialing. In addition, it protects the switch from electrical overloads and provides ringing, line supervision, and test circuitry. The equipment converts the analog voice signal into digital form and concentrates voice paths from several different subscriber lines onto a smaller number of digital paths into the switching network.
2. The control processor interprets dialed digits and establishes a path through the switching network to the called party.
3. The switch matrix supplies the signal path from the input (caller) to the output (called party) for the duration of the call.
4. Assuming that the called party is served by the same switch, the path terminates at the peripheral equipment (a different line card) serving another subscriber connected to this switch.

When the called party is a subscriber served by a different switch, the call must be routed over the interoffice trunk network to the destination switch.[2] Transmission facilities linking the local switch to other offices are connected to the switch by additional peripheral equipment for terminating trunks.

An interoffice call is routed from the originating line, through the switch matrix, to an outgoing trunk. A digital trunk obtains signals from the switch matrix in digital form and conveys them directly to the trunk facilities. Unlike the termination of analog lines, these digital trunks require no analog-to-digital conversion.[3]

The capacity of a digital switch to provide local network services is limited by the capacity of each primary functional component. The total number of lines and trunks cannot exceed the capacity of peripheral equipment; the peak flow of traffic cannot exceed the capacity of the switch matrix to provide connections; and the maximum rate of attempts and special service requests cannot overload the common

[2]Large metropolitan central offices may house more than one switch. Calls between these switches travel on short trunk cables within the same building. We include all interswitch traffic in the term "interoffice calls."

[3]An incoming call arriving on a digital trunk from another office follows the reverse path: It is routed through the switch matrix to the terminating line.

control processor. These capacity constraints are interdependent, and additional lines and greater calling increase the utilization of all components.

Variations in Digital Switches

The major digital switches used in California are broadly similar. Some differences in their architectural features affect the degree to which capacity can be expanded.

- The 5ESS switch (AT&T) incorporates a semi-autonomous processor in each interface module. Calls connecting subscribers whose lines terminate at the same module are switched within the module. Calls to other subscribers are connected through a single switch matrix. A central processor supervises intermodule traffic and supplies administrative services.
- The DMS100 switch (Northern Telecom) uses separate processors in peripheral units to scan lines and collect dialed digits. The switch matrix is expandable from one to 64 switch matrix modules. A single central message processor provides central control services.
- The GTD-5 switch (AG Communication Services) is controlled by one or more central processors that can be added to expand capacity. The switch matrix consists of time-division components, which are expandable from one to 64 units, plus the space switch, which can be doubled once.

All three switches permit modular addition of line and trunk peripheral equipment and variation in the rate at which lines are concentrated onto paths to the network switch. Each switch can also use digital trunk units to concentrate lines at remote locations and to service remotely located switches.

The variations in switch architecture mean that the coefficients of our model's equations, and the sensitivity of incremental costs to demand factors, will differ by switch. The values estimated below span this range of costs.

COST EQUATIONS

The number and types of components built into a particular local switch are determined from an engineering study, using both historical data and projected growth for the local area. Switches are engineered

by forecasting a basic set of sizing variables (as well as many secondary variables):

- Number of lines and number of trunks,
- Originating plus terminating busy-hour traffic,
- Number of busy-hour calls and busy-hour use of features,
- Outgoing plus incoming (interoffice) busy-hour traffic, and
- Amount and type of remote switching and line-concentrating equipment.

In North America, traffic engineering's primary measure of usage is CCS—hundred call-seconds—equal to 1.67 minutes of use. Originating traffic includes traffic flowing into the switching network through the switch matrix, plus dialing time and time for calls that are not completed when a subscriber misdials and hangs up the phone. Terminating traffic includes ringing and busy signals as well as conversation time, but it excludes dialing and other usage that does not result in a completely dialed number. Busy-hour usage is measured as the number of CCS in the peak hour in a weekday sample of the busiest weeks of the year.

We can restate the switch sizing factors in terms of number of lines and busy-hour measures of usage per line—variables that characterize demand in a model community for local telephone access and usage. The resulting demand variables are:

l = number of lines,
u = busy-hour originating usage in CCS/line,
a = busy-hour attempts/line,
n = fraction of originating busy-hour usage that is completely dialed and flows into switching network,
ι = fraction of network busy-hour usage destined for another switch (interoffice).

Trunking

To obtain the volume of interoffice traffic, we make the simplifying assumption that the local switch is connected to a similar office that has the identical demand values. With this assumed symmetry, each office will have equal amounts of outgoing and incoming traffic at the same busy hour.[4]

[4]With symmetric traffic flows, this is equivalent to calculating the incremental cost of outgoing traffic only and accounting for the additional costs of terminating that traffic in another central office.

We calculate trunking requirements by first determining the amount of originating usage that consists of calls to another office and then allowing an equal amount for incoming traffic:

$$\begin{aligned}\text{Outgoing CCS} &= \text{interoffice fraction} \cdot \text{network fraction} \\ &\quad \cdot \text{originating CCS / line} \cdot \text{lines} \\ &= i \cdot n \cdot u \cdot l \\ \text{Trunk CCS} &= \text{outgoing CCS} + \text{incoming CCS} = 2(\text{outgoing CCS}) \\ t_u &= 2 \cdot (i \cdot n \cdot u \cdot l)\end{aligned}$$

Trunk-termination equipment and interoffice trunking facilities are sized in multiples of 24 traffic trunks—a T1 span. The statistical capacity of a single traffic trunk within a T1 span (CCS_per_trunk) is derived in traffic engineering from the designed blocking probability and the form of the random distribution of the traffic. The number of trunks required is:

$$\begin{aligned}\text{Number of trunks} &= \text{trunk CCS / CCS per trunk} \\ t &= t_u \,/\, \text{CCS\_per\_trunk}\end{aligned}$$

AVERAGE INCREMENTAL COSTS

Cost Coefficients

As described above, the technology of a digital switch allows modular increases in capacity in several dimensions. In principle, each module in the switch has an average incremental cost—its investment cost divided by its capacity, plus associated operating expenses. The sizes of the capacity lumps, and the interdependencies of peripheral, switch matrix, and processor capacities differ according to the model of switch. In the process model, we approximate these relationships with cost functions that are linear in the capacity variables.

The (investment) cost parameters are:

g = getting-started cost per switch,
c_l = termination cost per line,
c_t = termination cost per (digital) trunk,
c_a = usage cost per (busy-hour) attempt,
c_u = usage cost per (busy-hour) originating CCS.

Total investment cost is:

$$C = g + c_l \cdot \text{lines} + c_t \cdot \text{trunks} + c_a \cdot \text{attempts} + c_u \cdot \text{CCS}$$

The total switch capacity is constrained by a maximum number of line and trunk terminations, the number of switching paths through the switch matrix, and the capacity of the processor to handle call attempts, features, and administrative services.

A central office switch is sized to carry nearly the peak volume of its total originating and terminating traffic—local calls, interexchange calls, and administrative traffic. The required capacity is therefore greater than that needed to serve only local and interoffice calls.

Switching and trunking capacity must be expanded when peak demand increases. Traffic engineering guidelines cause rationing of about 1 percent of usage during the peak hour of the busiest week of the year. These grade-of-service standards embody engineering judgment concerning the tradeoff between the cost of additional capacity and the value of lost calls.[5] Outside of busy-hour periods some capacity is idle, and thus there is virtually no incremental cost of additional usage during those hours.

We calculate the incremental investment, but not the total investment, required to serve the greater demand for local and interoffice traffic. The increment in capacity required to handle increased usage for other types of traffic would be similar, after accounting for differences in the fraction of traffic requiring trunking.

Cost Data

Switch manufacturers establish component prices on the basis of material and manufacturing costs, desired margins, and market conditions. They recover the development costs of switching systems and software by allocating those costs to components in several ways.

Telephone network planners evaluate alternative switches and options by using price profiles supplied by each vendor as well as specialized software, such as BellCore's Switching Cost Information System (SCIS) model. The proprietary price profiles aggregate the individual switch components into major categories that are distinguished by a small number of basic parameters and a list of optional and custom features. The resulting estimates of total cost are intended to approximate the sum of the costs of the components—the final price when the switch is ordered.

[5]For an economic analysis of peak-hour quantity rationing see Park and Mitchell (1987).

We employ cost data based on price profile information and on results obtained from running the BellCore SCIS switching model on various sets of model community parameters. Differences in switch architecture and vendor pricing yield a range of investment cost coefficients:

g = \$150,000–\$400,000 per switch,
c_l = \$80–\$125 per line,
c_u = \$8–\$26 per busy-hour originating CCS,
c_a = \$1–\$3 per busy-hour attempt, and
c_t = \$200–\$350 per trunk termination.

The values include investment in spare parts and test equipment. Getting-started costs include, in addition to vendor prices, a 15 percent factor for local engineering, power, and miscellaneous costs.

The cost coefficients represent the average incremental investment, per unit of capacity, that is required to increase the number of lines and trunks terminated and the volume of busy-hour traffic carried. To convert these values into the average incremental costs of basic telephone access and usage services at the local switch, we first calculate the average incremental costs of the three main outputs of the switch—subscriber lines, busy-hour call attempts, and busy-hour traffic (measured in CCS). These values are converted to an annual cost using a 15 percent real cost of capital and assuming periodic replacement based on economic lives of major components. AIC of access is then expressed as dollars per access line per year. AIC of usage is expressed as dollars per busy-hour attempt per year and dollars per busy-hour CCS per year. Finally, we translate the demands for access and local usage in a model community into these output requirements.

Line Termination

At the switch, access to the local network requires one line termination per line.

$$\begin{aligned}\text{AIC per line} &= \text{annual factor} \cdot \text{termination cost per line}\\ &= \text{annual factor} \cdot c_l \,/\, \text{designed utilization rate}\end{aligned}$$

The designed utilization rate, approximately 95 percent, provides a small margin to facilitate line rearrangements among line cards.

Attempts

Additional busy-hour dialing requires added switching capacity to process all originating call attempts plus incoming calls that arrive from other switches, whether or not the calls are completed.

$$\text{AIC per busy-hour attempt} = \text{annual factor} \cdot c_a (1 + i \cdot n)$$

Traffic

Additional minutes of busy-hour traffic require added network switch capacity for both originating and terminating traffic. We assume that for each CCS of originating traffic, there is an additional fraction i of terminating traffic that originates in other switches. The interoffice traffic also requires capacity in the trunk terminating units of the switch.

$$\begin{aligned}\text{AIC per busy-hour originating CCS} = \text{annual factor} \cdot\\ [c_u \cdot n \quad &\text{originating traffic}\\ + c_u \cdot (1 - i) \cdot n \quad &\text{terminating intraoffice traffic}\\ + c_u \cdot i \cdot n \quad &\text{terminating interoffice traffic}\\ + c_t \cdot (2 \cdot i \cdot n) / \text{CCS\_per\_trunk}] \quad &\text{interoffice traffic}\end{aligned}$$

Getting-Started Costs

A digital switch is normally selected to have sufficient capacity to meet 15 or more years of expected growth. Moreover, to a large extent digital switches have been installed to replace older technologies to reduce annual switch maintenance expenses rather than to relieve a situation of capacity exhaustion. We have calculated AIC assuming that these ultimate capacity constraints are never binding, so that the getting-started costs are indeed fixed costs.

In a community in which demand growth will exhaust the total switching capacity and require installing an additional switch, getting-started costs would also be incremental. An increase in output would cause the getting-started costs to be incurred at an earlier date. These costs may be incremental to access (if additional lines alone lead to exhaustion), incremental to usage (if greater usage per line becomes the binding constraint), or incremental to both.

Maintenance

The introduction of electronic switching technology has significantly reduced the costs of maintaining switching equipment. Modern digital switches have no moving mechanical parts and physical repairs often consist of technical diagnosis and replacement of electronic boards with spares. Software maintenance is normally performed from a central maintenance facility; as a result many central offices operate unattended, monitored by alarm circuits.

Like their outside plant counterparts, switch maintenance technicians perform both repair and change-order tasks. We have already included spare switching equipment parts in the incremental investment coefficients of the model. We estimate recurring repair account expenses are 3.5 to 4.5 percent of incremental investment annually. We have allocated these expenses to the functional categories of the local switch in proportion to investment.

RESULTS

The intensity and pattern of telephone usage differ across communities. Table 7 shows the average incremental costs and fixed costs for three community settings, selected to depict the variation in usage and size encountered in California central offices.

Table 7

SWITCHING: AVERAGE INCREMENTAL COSTS AND FIXED COSTS
(Dollars per year)

Community and Usage Characteristics	Average Incremental Cost per: Line	Attempt	Originating CCS	Fixed Costs per Line
Small urban (10,000 lines) 1.6 originating CCS/line, 1.8 attempts/line, 20% CCS interoffice	17–26	0.3–0.9	3–5	5–11
About-average (20,000 lines) 2.0 originating CCS/line, 2.1 attempts/line, 60% CCS interoffice	17–26	0.3–0.9	5–10	5–10
Larger urban (40,000 lines) 2.5 originating CCS/line, 2.8 attempts/line, 75% CCS interoffice	17–26	0.3–0.9	5–10	5–9

NOTE: Originating CCS = hundreds of call-seconds originating in busy-hour. Attempts = call attempts in busy-hour. At 1988 prices.

Getting-started costs are reported in the form of fixed costs per line. If growing demand is expected to require duplication of the switch, these costs should be considered incremental to the one or more demand components that cause capacity to be fully utilized, as discussed above.

These general findings emerge:

- Average incremental costs per additional line vary by type of switch, but for a given type are the same over a range of California conditions.
- Average incremental costs of usage also vary by type of switch and depend on busy-hour calling rates. Per minute of busy-hour traffic, costs are higher in communities with a large fraction of interoffice calling.
- Call attempts incur small incremental costs at busy hours.
- Increased usage outside of busy-hour periods incurs negligible incremental costs.

IV. INTEROFFICE TRANSPORT

Traffic between local central offices is carried on a variety of interoffice transport facilities, principally metallic cable, fiberoptic cable, and microwave radio links. In California, single-mode fiber is now the dominant technology for expanding capacity at distances greater than about three miles.

The interconnection of central offices by fiberoptics involves combining a large number of separate message channels into high-frequency, high-capacity signals; converting the electrical signals to light; and transmitting the lightwave over the fiber cable. At the destination office the process is reversed: The lightwave is converted to a high-speed electrical data stream and then split into the separate message channels.

The maximum capacity of an interoffice transport facility is determined by the number of fiber pairs (one fiber is used for transmission in each direction) and the transmission rate. Single-mode fiber cables are typically available with 6, 12, 24, or 48 pairs. The maximum transmission rate has been rising rapidly because of technological advances in electronics and optics, and the industry expects that it will be possible to continue to increase the effective capacity of existing cables by upgrading the opto-electronic transmission components.

STYLIZED TECHNOLOGY

Digital transmission systems are composed of successively larger-capacity elements. We describe the major components of a high-capacity, 405 Mbps (megabit per second) fiberoptic system typical of those used to interconnect a number of central offices in California.

The system begins with the fundamental DS1 level, which is equivalent to 24 voice channels (Fig. 7). DS1 signals from the local switch (or from other sources such as private lines) are connected to the system through a cross-connect device. Twenty-eight signals are then combined by a multiplexer into one DS3 signal.

The figure shows local switch trunk-terminations units as the only source of traffic for the transmission system. In practice, the system will also obtain traffic from DS1 private line circuits and in some cases from high bandwidth DS3 inputs. This traffic bypasses the

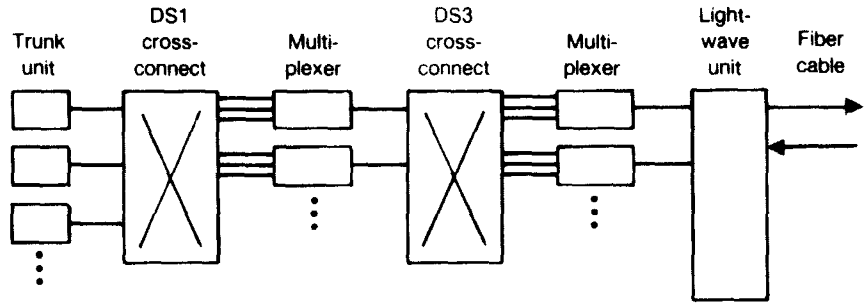


Fig. 7—Block diagram of interoffice transport

switch and enters the interoffice transport system at the digital cross-connect devices where it is combined with trunk traffic from the local switch.

At this intermediate transmission rate the several DS3 signals pass through a digital cross-connect device and are then combined by a high-frequency multiplexing unit, nine at a time, into the ultimate 405 Mbps data stream. The lightwave interconnect unit then inserts the laser-generated light beam into the fiber cable.

Two high-frequency data streams, traveling on a pair of fibers, are required to provide for traffic in both directions. In addition, fiber-optic cable facilities are engineered with standby components that provide protection in the case of a failure in the high-speed portion of the system. One protection pair is provided for every 7 to 15 active pairs, depending on design specifications; the equipment consists of standby multiplexers, a fiber pair, and a protection switch that can rapidly activate the standby link.

COSTS

Major portions of this system are required to supply just a single DS1 connection between central offices. The getting-started components include the fiber cable and associated underground structure, cross-connect devices, lightwave interconnect equipment, and a complete protection link. Typical investment costs at one end of the link are:

Cross-connects	$55,000
Protection components	
Protection switch	$10,000
Two 405 Mbps multiplexers	$80,000
Lightwave interconnect	$120,000
Total fixed components, one end	$265,000
12-fiber cable, per mile	$30,000

The significant variable components are the multiplexing units, which can be added as needed to increase effective capacity. Representative estimates of the investment costs of these items are:

Component	Per Component	Channels per Component	Per Trunk
DS1/DS3 multiplexer	2 × $15,000	28 × 24 = 672	$45
DS3/405 multiplexer	2 × $40,000	9 × 28 × 24 = 6,048	$13

The principal effect of greater interoffice traffic on maintenance expenses is due to the increase in multiplexing equipment used. We estimate incremental annual maintenance expenses as 1.5–2.5 percent of incremental interoffice investment.

RESULTS

The capacity required for interoffice transport depends directly on the volume of outgoing and incoming traffic at a central office.

The incremental investment to carry additional interoffice traffic is thus $45 to $58 per trunk. On an annual basis, using an economic lifetime of 12 years typical of circuit equipment, the average incremental capital cost is $0.41 to $0.53 per busy-hour CCS transported between central offices.

Table 8 shows these costs for the three model communities. Because only a fraction of all local calls require interoffice transport, the incremental cost per originating busy-hour CCS varies somewhat across communities.

Table 8

INTEROFFICE TRANSPORT: AVERAGE INCREMENTAL COSTS AND FIXED COSTS
(Dollars per year)

Community and Usage Characteristics	Average Incremental Cost per Originating Busy-Hour CCS	Fixed Costs per Line
Small urban (10,000 lines) 20% CCS interoffice	0.1–0.2	7
"Average" (20,000 lines) 60% CCS interoffice	0.4–0.6	3
Larger urban (40,000 lines) 75% CCS interoffice	0.5–0.7	2

V. EXPENSES

Although capital investment makes up a high proportion of the total costs of providing telephone service, one-time and recurring expenses are also significant.

We included the expenses of maintaining the local loop, central office switch, and interoffice transport facilities in the incremental cost calculations reported earlier. In this section we consider other major expenses directly associated with providing basic local service.

BILLING AND CUSTOMER ACCOUNT EXPENSES

The costs of billing and accounting for telephone service fall into three functional categories:

- Recording and processing call records
- Rendering a monthly bill, collecting payment, and maintaining an account
- Establishing and changing service

Accounting for the use of telephone services involves millions of monthly transactions and requires the continuous use of large mainframe computers.

Stylized Technology

The process of billing subscribers for local telephone access and calling follows several steps.

At the subscriber's central office the local switch causes a record of each completed call to be generated.[1] The records are accumulated by an adjunct computer processor linked to the telephone switch and periodically forwarded to a central processing center.

In most offices, data are accumulated on magnetic tapes. However, billing systems now being designed will connect central offices by dedicated data lines to the central processing point.

At the processing center the records from each office are sorted, validated, and corrected if necessary. Calls are "rated" by applying the tariff price applicable for each call. Completed transactions are then accumulated by customer account.

[1]If the call is a flat-rate call, no record or only a minimal record may be created.

Once a month, on a regular cycle for a given customer account, the processing center produces a total bill for the monthly calls, including an itemized listing of toll and message-unit (ZUM) calls, plus regular monthly charges for the customer's service, and any nonrecurring items. The bill is then stuffed into an envelope, stamped, and mailed.

Financial transactions are handled by the billing center. It receives subscriber payments and credits them to the customer account. It also handles inquiries and adjustments.

Incremental Costs

We have estimated the average incremental costs of billing calls and servicing an account from operating company expense records and from plans for new systems based on distributed data processing.

Incremental costs of billing for usage result from the creation of a data record for the call, processing the record in the accounting system, and printing the item on the monthly bill. We estimate that itemized billing of each call incurs an incremental cost of 0.7 cent to 1.2 cents per call. The incremental cost per call is lower, on the order of 0.1 to 0.2 cent, when calls are billed in summary form (only the total number of monthly local calls is reported) using distributed processing equipment.

We estimate the incremental costs of maintaining an active consumer account and issuing and collecting a bill to be $0.50 to $0.75 per month. This cost is in addition to the costs of billing for usage.

Nonrecurring Costs of Customer Account Activity

If a customer's premises are already connected to the local loop distribution facilities, making service available for a new subscriber requires only activating a local loop termination at the central office. If not, a technician must be dispatched to establish service at the site. In both cases new service also requires creating an account in the master customer account file and an entry in the directory assistance database.

Changes in service—from one tariff to another, or to add or remove a feature—require altering the master account file and often updating the translation information in the local switch.

New service orders and change-in-service orders are nonrecurring expenses. However, in the course of a year most of the customer account activity is due to account changes—subscribers who move their residence or business location and who add or change features. On average, some one-third of California residential accounts incur a change each year; only 10 to 15 percent of this activity represents a net increase in subscribers.

Estimates of the average incremental costs of nonrecurring expenses per service order associated with account changes are as follows:

Connect plus disconnect service	\$25–\$45
Visit premises	\$60–\$75
Change/move service	\$7–\$15

OTHER EXPENSES

In this study we have accounted for the costs of capital investment by applying an annualization factor to the original investment cost of capital equipment. This cost of capital in real terms (net of inflation) includes interest payments on debt and return to equity, and corporate income taxes, and provides for periodic replacement of equipment at the end of its economic lifetime.

Our analysis of operating and nonrecurring expenses is not exhaustive. The local exchange carrier also incurs major expenses for marketing, operator and directory-assistance services, general administration, property taxes, legal and regulatory affairs, moving and rearranging subscriber lines, and a variety of nonrecurring items. While many of the activities in these categories support particular products, some increases in administrative and regulatory expenses could be associated with an increase in local access lines.

VI. ACCESS AND USAGE COSTS

In the previous four sections we modeled the average incremental costs of increasing the principal outputs of the local loop, local switch, and interoffice transport components of the local exchange network. In this section we combine these results to estimate the average incremental costs of the two principal products of the local exchange carrier—basic access and local telephone use. These products have been sold under separate tariffs to residential and business customers. Consequently, we also estimate the average incremental costs of typical residential and business lines used for local exchange service.

ACCESS

Basic access service provides a voice-grade connection from the subscriber to the local switch. The access service is needed for local calls, interexchange calls, and special services and features. The incremental costs of access consist of the incremental costs of a local loop (one loop is required regardless of the amount of usage) plus the incremental costs of terminating the line at the switch (which varies by type of switch). Access-related maintenance costs are incurred for repairing the local loop and for servicing line-termination equipment at the local switch. On an annual basis, these costs (Table 9) range from some \$53–\$66 per line in high-growth urban areas to about \$141–\$158 per line in outlying, slow-growing communities.

As noted earlier, local loop costs vary substantially within areas of similar density. Some lower-density communities have incremental access costs no greater than those calculated for a model "large urban" community. Conversely, other dense urban areas with longer loops have higher incremental costs.

USAGE

The incremental costs of usage, which vary by type of switch, are determined by busy-hour minutes of conversation and to a small extent by busy-hour attempts. Maintenance expenses vary in proportion to switch investment. Per minute of average local calling, additional usage is more costly in communities with a high proportion of interoffice calling, because of the greater need for trunk-terminating equipment at the switch and additional interoffice transmission facilities.

Table 9

LOCAL EXCHANGE: AVERAGE INCREMENTAL COSTS
(Dollars per year)

Item	Small Urban	"Average"	Larger Urban
Access—per line			
Loop investment	104	42	29
Loop maintenance	15-20	2-4	1-3
Switch investment	14-22	14-22	14-22
Switch maintenance	3-4	3-4	3-4
Billing	6-9	6-9	6-9
Total	141-158	67-80	53-66
Local Usage—per busy-hour originating CCS			
Switch investment	3-5	5-10	5-10
Switch maintenance	1-.2	.2-.4	.2-.5
Interoffice	.2	.5	.6
Total	3-6	6-11	6-11
Local Usage—per busy-hour attempt	.3-.9	.3-.9	.3-.9
Local Usage—per 100 calls/month summary billing	1.2-2.4	1.2-2.4	1.2-2.4

NOTE: Derived from Table 6 (loop), Table 7 (switch), and Table 8 (interoffice). At 1988 prices.

Expenses for billing local usage depend on the total number of calls and whether individual calls are itemized. Per 100 calls a month, summary billing adds $1-$2 annually to local exchange costs.

FIXED COSTS

Table 10 shows substantial fixed costs, most of which are the costs of the neighborhood distribution portion of the local loop. In addition, local exchange service incurs other fixed costs for land, portions of the local loop, buildings, and corporate overhead, which have not been estimated.

RESIDENTIAL AND BUSINESS COSTS

In many jurisdictions a local measured service tariff is used to price access and local usage separately. In most states, however, flat-rate service remains the predominant rate for residential subscribers. It is therefore of interest to calculate an incremental cost of the bundled service—access plus usage.

Table 10

LOCAL EXCHANGE: FIXED COSTS
(Dollars per year)

Type	Small Urban	"Average"	Larger Urban
Fixed cost (per line)			
Loop	164-165	60-61	45
Switch	5-11	5-10	5-9
Interoffice	7-8	4	2
Land, buildings	NA	NA	NA
Total	176-184	69-75	51-57

NOTE: Derived from Table 6 (loop), Table 7 (switch), and Table 8 (interoffice). At 1988 prices.

Table 11

TYPICAL LOCAL EXCHANGE PARAMETERS,
RESIDENTIAL AND BUSINESS LINES

	Small Urban		"Average"		Large Urban	
Parameter	Res.	Bus.	Res.	Bus.	Res.	Bus.
Feeder length (ft)	14,000	10,000	10,000	9,000	6,500	5,000
Distribution length	4,000	2,000	2,000	1,500	1,500	1,000
Busy-hour originating CCS/line	1.2	1.8	2.0	2.0	2.0	2.8
Busy-hour attempts/ line	0.9	2.3	1.5	2.5	1.5	3.4
Percentage interoffice	20	20	50	65	70	80
Growth rate	Low	Low	Med.	Med.	High	High
Construction	Aerial	Aerial	Under-ground	Under-ground	Under-ground	Under-ground

We can estimate the average incremental costs of serving a typical residential customer and a typical single-line business customer by applying the estimated cost parameters to representative usage rates for the two types of customers. We use a variety of local exchange traffic studies to obtain the busy-hour CCS and attempt rates shown in Table 11.

We continue to illustrate costs with the same three model communities examined above, but now the parameters are specific to each group of subscribers—residence or business—rather than to the weighted average of the two.

We calculate that a typical residential subscriber in a model community with "average" characteristics has an average incremental cost of access, including the expenses of monthly billing, of \$67–\$80 annually. The typical subscriber's busy-hour usage incurs an average incremental cost of some \$13 to \$24 per line annually (Table 12) for a total incremental cost per residential line of \$79–\$104. If local calling is billed on a measured-service basis, expenses for measuring and summary billing would add \$8–\$16 per year for the average subscriber. The variations in local loop construction and central office switching technologies account for the range of incremental cost estimates.

Residential subscribers in larger urban communities have slightly lower total incremental cost per line than subscribers in an "average" community, where access costs are lower but usage costs greater. In small urban areas where longer, aerial loops are the norm, subscriber lines have much higher incremental access costs.

In many communities, the more central location of business subscribers causes their total incremental costs to be lower than those of residential subscribers. In larger urban communities, however, business costs are slightly higher than those of residential users. Although business users also have shorter loops in these communities, the differences are smaller, and they have greater busy-hour usage.

Table 12 reports estimates for three types of communities. Across the state, communities vary a good deal in characteristics that affect incremental costs. The range of incremental costs of access and usage costs encountered in individual communities is thus broader than the values summarized here.

Table 12

AVERAGE INCREMENTAL COSTS OF ACCESS AND USAGE
(Dollars per year)

Access/Usage Characteristic	Small Urban	"Average"	Larger Urban
Residence			
Access	152–169	67–80	53–66
Usage per line	5–10	13–24	14–27
Access plus usage	158–179	79–104	67–93
Business			
Access	111–126	62–75	46–59
Usage per line	7–15	14–27	21–39
Access plus usage	118–141	76–102	67–98

VII. TANDEM SWITCHING AND INTRA-LATA TOLL CALLS

Thus far we have investigated the costs of access to the network and the costs of local exchange usage—calls between subscribers served by the same local switch or by two different switches directly connected to each other by the interoffice transport network. These local calls account for some 80 percent of all residential calling.

Most of the remaining telephone usage consists of calls between subscribers who are not located in the same community.[1] These longer-distance calls are routed through an intermediate *tandem switch* that connects a local switch to an intercity network. In this section we extend the process model of the local exchange to include tandem switching and estimate the incremental costs of such calls when they are supplied entirely by the local exchange carrier. Broadly speaking, these are calls within a metropolitan area or to nearby communities.

Most "long-distance" calls involve two or three separate carriers—the local exchange carrier of the originating caller, an interexchange carrier that transports the call to the destination community, and the local exchange carrier of the called party. We have not analyzed interexchange carrier costs, and our incremental cost estimates therefore do not apply to such long-distance calls.

STYLIZED TECHNOLOGY

Intercity transport of telephone calls may be provided by the local exchange carrier, in the case of calls within the local transport area (intra-LATA calls[2]), or by interexchange carriers on the LEC's own intercity network. In this case the call is delivered to another access tandem switch at the destination area.

Figure 8 illustrates several traffic paths that might connect subscribers A and B in different locations. Direct paths are used to connect central offices within a community or in a portion of a metropolitan area when the two offices are at most a few miles apart and have a

[1]Other types of usage—including operator services, credit-card calling, and directory assistance—are not considered in this study.

[2]A LATA (local access and transport area) is a geographic region created by the Modified Final Judgment that settled the AT&T antitrust suit. A Bell Operating Company may transport calls within, but not between, LATAs. California is divided into 11 LATAs.

high volume of traffic (Fig. 8a). With greater distances and lesser traffic it is more efficient to bring the traffic from several central offices together at one access tandem (Fig. 8b). In larger cities and when the subscribers are more distant it is necessary to switch the traffic at two tandems (Fig. 8c).

In the case of calls that are transported by an interexchange carrier, a call travels from the central office to a local exchange carrier's *access tandem* where it is switched to the point of presence (POP) of the interexchange carrier designated for that call (Fig. 8d). The call moves into that carrier's network for switching and transport to a second POP at the destination area, where it is then passed on to another access tandem and finally to the destination central office.

In addition to the extra switching required, intercity calls require additional transport links. We assume the switching points are connected by high-capacity fiberoptic cables.

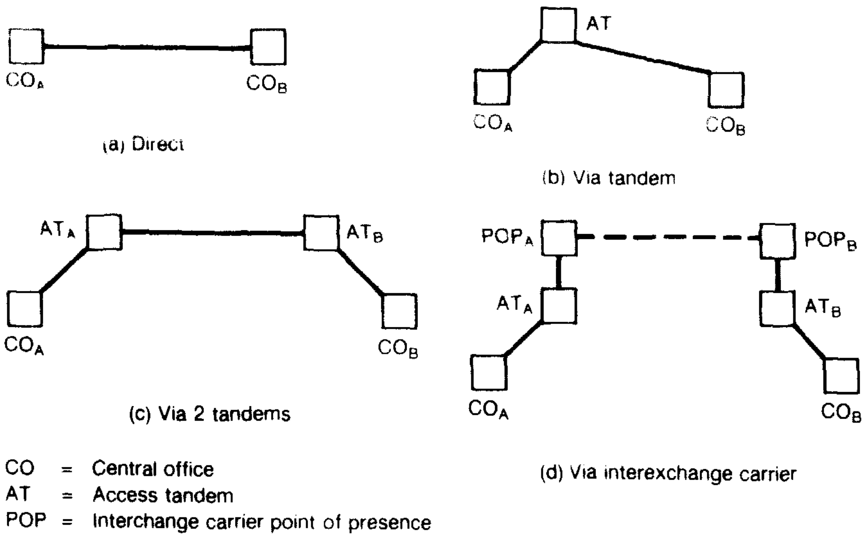


Fig. 8—Interoffice traffic paths

INCREMENTAL COSTS

As compared with calls that travel directly between two central offices, tandem-switched interoffice calls incur additional switching and transport costs. We model these additional costs with the same functional components used in the local network, identifying incremental switching resources and incremental transport.

Tandem switches are used to switch traffic within the telephone network; unlike central office switches they do not connect directly to subscribers' lines. Therefore, these switches have no line cards, but do have a large number of trunk units that connect to interoffice (fiber or copper) trunk facilities. Most tandem switches are digital and designed to carry large volumes of traffic.

Increases in busy-hour traffic handled by the tandem switch require additional trunk units and switching components. Transport links likewise require additional multiplexing equipment.

From vendor price profile data and results from running the BellCore SCIS switching model we obtain incremental investment coefficients for tandem switching:

c_u = \$3–\$5 per busy-hour CCS,
c_a = \$1–\$1.50 per busy-hour attempt, and
c_t = \$200–\$350 per trunk termination.

Annual incremental maintenance expenses for tandem switches are estimated to be 3.5–4.5 percent of incremental investment. For maintenance of interoffice transport facilities, annual maintenance is estimated to be 1.5–2.5 percent of incremental investment.

USAGE AND TARIFFS

Intercity and tandem-switched calls, usually billed differently from calls within the local exchange area, are often referred to as *toll*, *trunk*, or *long-distance* calls.

In California, the local exchange calling area generally consists of the telephones served by a subscriber's own central office plus those in geographically adjacent offices. Calls to more distant offices are billed on a usage-sensitive basis, with the rate increasing in a series of distance bands.

Within an urban area in California, Zone Usage Measurement (ZUM) rates apply to calls of 9 to 16 miles, where the distance is measured between central office locations. The first minute of daytime calling is 8 or 10 cents, plus 2 or 4 cents per additional minute. For other calls within the local access transport area—to different cities and over longer distances—a distance-sensitive rate applies. It is approximately 10 cents per call plus a charge of between 7 and 31 cents for each minute. The rates are reduced after 5 p.m. on weekdays, and are further reduced at 11 p.m. and on weekends. The 1989 tariff is shown in Table 13.

Nonlocal calling accounts for a significant fraction of a local exchange carrier's total message traffic in California. In addition to their local calls, residential subscribers make another 10 percent of those calls to nearby ZUM areas, and another 10 percent to intra-LATA destinations (Table 14). Business subscribers make more intensive use of their lines for both local and intercity calling. Comparative revenues per line are shown in Table 15.

Incremental Costs of Tandem-Switched Calling

Some 40 percent to 60 percent of the ZUM calls travel through a tandem switch; the remainder are routed directly between the originating and terminating offices. Intra-LATA toll calls require at least one,

Table 13

ZUM AND INTRA LATA TOLL RATES
(Dollars per minute)

Mileage Band	ZUM First Minute	ZUM Additional Minute	Intra-LATA Toll First Minute	Intra-LATA Toll Additional Minute
0–8			.17	.07
9–12	.08	.02	.17	.07
13–16	.10	.04	.20	.10
17–20			.22	.13
21–25			.25	.16
26–30			.28	.19
31–40			.31	.22
41–50			.34	.25
51–70			.37	.28
71+			.40	.31

NOTE: Rates and rate periods are:

Mon Fri	8am 5pm	full rate
	5pm-11pm	30% discount
	11pm- 8am	60% discount
Sat, Sun	all hours	60% discount

Table 14

MONTHLY TELEPHONE USAGE
("Average" exchanges)

Usage Characteristic	Local	ZUM	Intra-LATA Toll
Residence			
Calls	119	12	11
Billed minutes	459	37	51
Minutes/call	3.9	3.0	4.5
Business			
Calls	189	29	36
Billed minutes	417	72	103
Minutes/call	2.2	2.5	2.9

NOTE: ZUM: 9–16 miles.

Table 15

MONTHLY REVENUE PER LINE

Type of Line	Basic Local[a]	ZUM[b] Toll	Intra-LATA Toll
Residence	$11–12	$1.30	$6.80
Business (single line)	23–up	4.40	18.50

[a]Includes subscriber line charge.
[b]Includes operator services.

and frequently two stages of tandem switching; the likelihood of using a second tandem increases with the call distance.

Because of tandem switching the incremental costs of usage for most ZUM and intra-LATA toll calls are greater than for local usage. In Table 16 we show estimates of average incremental costs per busy-hour CCS and per busy-hour attempt for three categories of calls—local usage, ZUM bands, and intra-LATA toll. The estimates for local calls include the proportion of interoffice calls assumed earlier, and the ZUM and intra-LATA toll categories assume a mix of direct routing and tandem switching typical for those types of calls.

Incremental costs for these calls at busy hours are some two to four times the AIC for local calls. In addition, itemized billing adds a cost of some 0.7 to 1.2 cents to each nonlocal call at all hours.

Table 16

AVERAGE INCREMENTAL COSTS OF USAGE

Type of Usage	Local	ZUM	Intra-LATA Toll
Per bh CCS	$3-11/yr	$8-17/yr	$12-35/yr
Per bh attempt	$0.3-0.9/yr	$0.4-1.2/yr	$0.6-1.8/yr
Per 100 calls	$0.1-0.2 (summary)	$0.7-1.2 (detailed)	$0.6-1.2 (detailed)

NOTE: Rates and rate periods are:

Mon-Fri	8am-5pm	full rate
	5pm-11pm	30% discount
	11pm-8am	60% discount
Sat, Sun	all hours	60% discount

VIII. APPLICATION OF INCREMENTAL COST METHODOLOGY TO OTHER SERVICES

In the previous sections of this study we described a basic methodology for estimating the incremental costs of local exchange services. We then developed a small engineering process model to represent the essential technology used to produce those services and estimated ranges of parameter values that represent conditions in California. The model provides broad-gauge measures of the incremental costs of basic access service and telephone usage for local and intra-LATA calling.

Although basic service is a local exchange carrier's largest business, the local exchange carrier (LEC) produces a wide range of additional telecommunications services. In this section we briefly examine how our methodology can be applied to four categories of services. Two of those categories—centrex and private lines—are major, mature products purchased by many different types of business customers. The other two—voice mail and 800-database services—are new products that exploit technologies just now being introduced into the local exchange network. These newest services may be produced by the LEC, by another "enhanced service" provider, or by both types of firms in direct competiton.

Each type of product requires access or usage services from the local exchange in addition to more specialized resources. Our incremental cost model of basic exchange service thus provides an essential foundation for a more extended analysis of the particular technology and features of each service. In this section we describe the major cost components that would be included in such an analysis and the sources of relevant data needed. The project's scope did not allow us to calculate numerical estimates of incremental costs for these products.

THE CENTREX MARKET AND SERVICES

Local exchange companies offer subscribers a broad range of business telephone services under the general name centrex.[1] Many of its features provide private switching service to facilitate communication within an organization, which may be located in more than one local building.

[1]GTE's centrex service is termed CentraNet.

Centrex appeals to a wide range of businesses. Small organizations typically purchase a standard bundle of features. Such packages may include direct dialing, call transfer, call forward, abbreviated dialing, speed calling, call waiting notification, and conference calling. Larger business customers frequently add additional features, selecting those appropriate to their requirements. More than one hundred different features are offered.

Some 800,000 lines in California have centrex service. However, LECs face vigorous competition from private branch exchange (PBX) vendors. A PBX, consisting of switching equipment installed on the customer's premises, provides many of the most popular centrex services.

Stylized Technology

To produce centrex service the local exchange carrier connects each standard telephone station at the subscriber's premises to the central office by a separate access line. In the central office, additional software in the local switch monitors call attempts on centrex lines and provides many special features. Other features, such as an attendant's console for answering a number of lines, also require specialized customer equipment, which may be connected to the switch by data lines as well as voice lines. Several additional features, such as conference calling, are produced using special-purpose hardware at the local switch.

Components of Incremental Costs

In concept, incremental costs of access and usage for centrex subscribers are similar to incremental costs for single-line subscribers.

Each centrex telephone station has a POTS access line to the central office, terminating in a line card at the local switch. Average incremental cost of local loop access can be estimated by using the appropriate construction and growth conditions for the local community. However, the length of a centrex local loop may differ significantly from average community values. In California, centrex customers are typically located some 1000 feet closer to central offices than are single-line businesses. As a result, AIC for centrex access is, on average, lower than for other business lines.

The busy-hour usage of centrex lines has a greater impact on central office switching requirements than busy-hour use of single-line business lines. Compared with a basic line, calling on a centrex line requires increased switch processing to detect and activate particular features. Basic direct outward-dialing ("dial-9") itself occupies the

processor for a longer period than comparable single-line calls. The AIC per busy-hour attempt is therefore higher. The AIC per busy-hour centrex attempt can be estimated using switch vendors' data on the processing time required for different types of calls, and combining this with data on the mix of centrex call types at busy hours.

Once a connection is established, the AIC per minute of calling on a centrex line will be the same as for a POTS line. However, the intensity of busy-hour usage of centrex lines differs from that of single-line businesses and should be estimated from traffic studies of subscriber line use.

The incremental costs of offering individual centrex features depends on the specific items. A particular feature generally increases costs in some or all of these categories:

- Software right-to-use fees
- Labor to configure features for each line
- Additional switch hardware
- Use of switch processing busy-hour capacity
- Accounting and billing services
- Additional customer premise equipment

We indicate sources of data and type of calculations needed to estimate incremental centrex costs for these categories.

Software and Nonrecurring Costs. Centrex features require enhanced versions of the basic switch software, and switch vendors recover additional software costs by various pricing strategies. The vendor may charge the LEC a right-to-use fee to provide a particular feature in these ways—once per switch; or for each line equipped with feature; or once per feature, or per group of features installed in any number of switches. Per-line and per-feature fees directly increase the LEC's incremental nonrecurring costs per line or feature. Fees levied on a per-switch basis are an incremental cost common to all centrex services.

When centrex service is first established for a customer, the LEC incurs nonrecurring labor costs to enter the feature data into the translation table for each line. For smaller customers who select a standardized package of features this cost can be estimated by applying broad-gauge direct labor factors to the average labor time needed to provision a centrex line. Larger customers often require a site visit to establish customized features for individual lines, and these initial costs should be determined from a study of service visit times. Each centrex line requires some dedicated memory to store information about its features.

Additional Central Office Hardware. Some centrex features require dedicated equipment, such as three-port conference equipment to provide three-way calling. This equipment, which may be common to several centrex lines, typically has a small capacity. To account for this cost, include the average investment or annual expenses per line in the incremental cost of the feature.

Additional Usage Costs. Individual centrex features require additional processing per call attempt that varies somewhat by feature. For such a feature, estimate the additional processor resources required per attempt from switch vendor studies.

Some features increase the average holding time of a call. Estimate the increase in CCS per busy-hour call that uses the feature and apply the AIC per busy-hour CCS to obtain the additional incremental usage cost of the feature per busy-hour call. Estimate from traffic study data the typical frequency of the feature's used during busy-hour periods. For usage not normally included in traffic studies (principally intercom calls between different lines serving a single centrex customer) estimates can be based on switch vendors' designed usage rates.

Accounting and Billing Services. Monthly accounting costs for a centrex customer vary with the number of lines and degree of billing detail. Estimate minimum costs per customer and per line for providing summary billing from AIC estimates of issuing monthly statements. Estimate the incremental costs of itemized billing per line from AIC estimates for recording and billing per-call usage.

Customer Premise Equipment. Equipment installed at the subscriber's location—including telephone stations, attendant consoles, message desk, and wiring inside the building—will normally be separately tariffed, or supplied by other vendors.

Summary

The incremental costs of centrex services are composed of AIC estimates for basic access and usage, adjusted for differences in the location and usage of centrex customers, plus the costs of additional busy-hour usage of switching equipment, and plus special-purpose equipment.

Incremental access cost per centrex line is the AIC per line for the construction and growth characteristics of the community, adjusted for the typically shorter feeder distance of supplying a centrex customer.

Incremental usage costs per busy-hour attempt will exceed AIC for POTS call attempts to the extent that additional processing is required on each call. In addition, specific features require further processing and additional processor memory.

Incremental usage costs for a centrex line also differ from typical AIC per line because of differences in centrex line usage patterns, and because of increased holding times per call for some features.

The establishment of centrex service in a central office incurs one-time costs. Software upgrades to the switch are a one-time incremental cost required for the totality of centrex lines and customers. Switch vendors may in addition levy per-line or per-feature charges. Establishment of feature service for each customer and each line incurs labor and provisioning expenses.

Centrex services incur recurring costs in excess of basic POTS calls. These include the annualized cost of additional switch memory and maintenance per feature, increased usage of the switch to process a busy-hour attempt, and an increase in the holding time of calls, as well as the cost of providing detailed billing per line.

PRIVATE LINES

Local exchange companies supply unswitched transport services under the general heading of "private lines" or "leased lines." Private lines are dedicated, 24-hour connections between two points that provide a defined level of technical quality and capacity.

Customers use private lines for a very wide range of applications, including fire and burglar alarms, dedicated voice circuits between plants, data circuits to link computers with point-of-sale terminals, PBX trunk connections to interexchange carriers, etc. Typically, one end of the private line circuit terminates at the customer's premises. The other end may terminate at another firm, or perhaps at other premises operated by the customer.

LECs are the principal suppliers of most types of private lines, and offer them in a range of analog and digital circuit capabilities. In addition, metropolitan area networks, linked by high-capacity fiberoptic private lines, are being developed to interconnect computer installations and interexchange carriers' facilities in urban areas. Increasingly, these facilities are supplied by other firms.

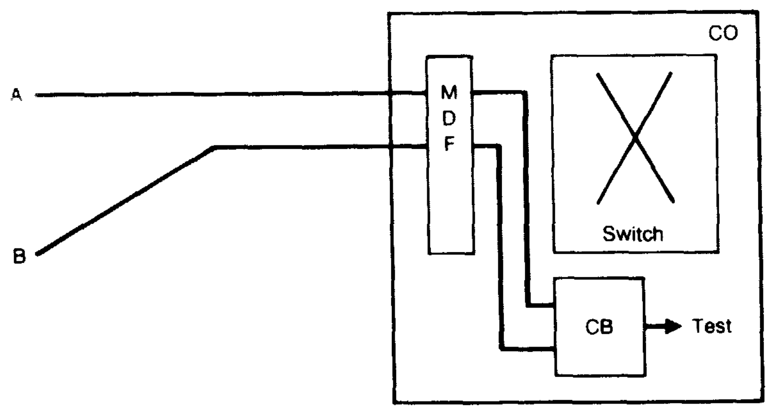
Stylized Technology

Private lines are typically provided using twisted-pair local loop facilities to connect the subscriber's premises to the wire center (central office) location. A single private line may involve a single twisted pair (for a voice circuit) or two pairs (a 4-wire data circuit). Additional loop or interoffice transport facilities then continue the connection to the point of termination.

At the subscriber's premises the line is terminated by electronic channel equipment, including "plug-in" modules for the specific type of service needed. When the line reaches the central office, it is not terminated at the line card in the local switch (as it would be if used for POTS access) but at central office channel bank equipment. Depending on the service and the distance of the customer from the office, a gain device, repeater, or other equipment may be connected to the line here. The channel bank termination also includes provision for test and maintenance access to the circuit. Figure 9 is a schematic diagram of one common configuration.

Private line services are made up to order. The LEC installs the channel equipment at the subscriber's location(s), and adds the needed central office equipment in the channel bank. Any segments of the interoffice network required to make up the complete private circuit are constructed by connecting circuit facilities together at cross-connect points in the network. Where a digital access and cross-connect system (DACS) is in place the circuit can be configured remotely.

Higher-capacity private line service is commonly provided on copper loops with digital T1 equipment. Multiplexing equipment may be needed at the subscriber's premises for T1 service; in addition, the



CO = Central office
CB = Channel bank
MDF = Main distribution frame

Fig. 9—Block diagram of private line service

copper loop requires an electronic repeater unit approximately every mile.

Still higher capacity service, currently used for video and high-bandwidth computer connections, requires a fiberoptic termination at the subscriber's premises.

The interoffice portions of private line circuits will be transported largely on backbone fiberoptic cables. A single circuit will be multiplexed with other traffic (from the local switch or other private lines), transported to the destination office, and demultiplexed and terminated in the private line at that end.

Incremental Costs

The incremental costs of a private line consist of the nonrecurring costs to set up (and eventually remove) the service, the incremental capital and maintenance costs of an access line to the central office equipped with the requisite electronics, and the corresponding costs of a second access line (or interexchange trunk) to the point of termination. Because traffic traveling over a private line does not use the local switch and the line is served by full-time dedicated electronic conditioning equipment, there is no incremental cost of line usage.

Access Cost. For each local loop segment of a private line circuit, estimate the incremental cost of a two-wire access line from the AIC value for local loop access, based on the distance of the subscriber from the central office and the type of feeder construction. Estimate the investment cost of plug-ins, multiplexers, gain devices, and other channel bank equipment at the customer's premises and the central office from itemized provisioning guides for the particular private line service. If the circuit includes an interoffice segment, estimate its incremental cost using the AIC value for interoffice CCS, assuming full utilization of an interoffice trunk.

Expenses. Estimate maintenance expenses for the outside plant of the local loop using POTS access line maintenance factors per mile and construction type. Apply maintenance factors for circuit equipment to the private line channel equipment in the central office.

Nonrecurring Expenses. Setting up a private line circuit requires significant engineering and provisioning activities. For the most common private line services, incremental expenses can be estimated from average work-order times per line and labor rates, distinguishing single-line and multiple-line installations. The expense calculation should also include the per-line cost of disconnecting the circuit. Special-order services would be calculated on an individual basis.

VOICE MAIL

Voice mail is a relatively new service that in its most basic form is similar to a home telephone answering machine. A voice mail subscriber can have his or her telephone answer calls with a prerecorded announcement and take a message from the caller; later the subscriber can retrieve the message. The elementary service can be augmented with a variety of features for filing, retrieving, and forwarding messages, including sending a single message to a list of addressees and retrieving messages when at a different telephone.

Voice mail service is supplied and sold by an unregulated voice mail (enhanced service) provider to telephone subscribers. The supplying firm produces the service with its own equipment, purchasing essential access and switching services from the local exchange company.

Although local exchange carriers may themselves supply voice mail service, both federal and state regulations require them to separate the cost of regulated and unregulated services.

Our focus is on the additional costs incurred by the LEC when voice mail service is offered by a voice mail provider. We describe typical voice mail services, examine the stylized technology for delivering voice mail, and review rates that have been considered in initial trials of this new service.

Services

In the basic form of voice mail, a telephone subscriber uses the service to answer his telephone—when he is not near the phone, *or* when he is busy using the phone—by playing a prerecorded announcement and allowing the caller to leave a voice message. In some systems the voice mail system will also automatically record the caller's telephone number when the caller is a nearby subscriber.[2]

When a message has been left, the system will notify the recipient that he has mail, usually by placing a "stutter-tone" on the line when he next uses the telephone. The subscriber can then dial a short code to cause the message to be replayed and, if the caller's number has been automatically recorded, use another short code to return the call.

Voice mail service will compete with somewhat similar services available today. These include personal answering machines at subscribers' premises, manual telephone answering services, and voice mailboxes offered by service bureaus.

[2]Automatic identification of calls currently requires that both the caller and the called number be served by the same local switch. Extending this feature to calls placed from more distant switches awaits the installation of common-channel signaling between local switches.

However, the voice mail technology may become the foundation for a host of new services that presently have few counterparts. For example, the voice mail answering equipment can be enhanced to route the call to secondary announcements and to use one of a series of mailboxes based on a digit punched by the caller in response to the first announcement. Calls may be forwarded to another office or another city. Fax messages could be recorded for later retrieval or broadcast to several addresses.

Stylized Technology

Figure 10 illustrates the flow of calls that typically occurs in the use of a voice mail system. Subscriber A places a call to B (panel 1). Because B's phone is busy, or does not answer, the call is routed from the central office to the voice mail machine, which plays the announcement and records a message.

Sometime after the message has been recorded, the central office notifies B that a message is waiting (panel 2). This is typically done by adding a distinctive stutter-tone to the line when B next picks up the telephone receiver. Some systems illuminate a small message-waiting light at B's telephone.

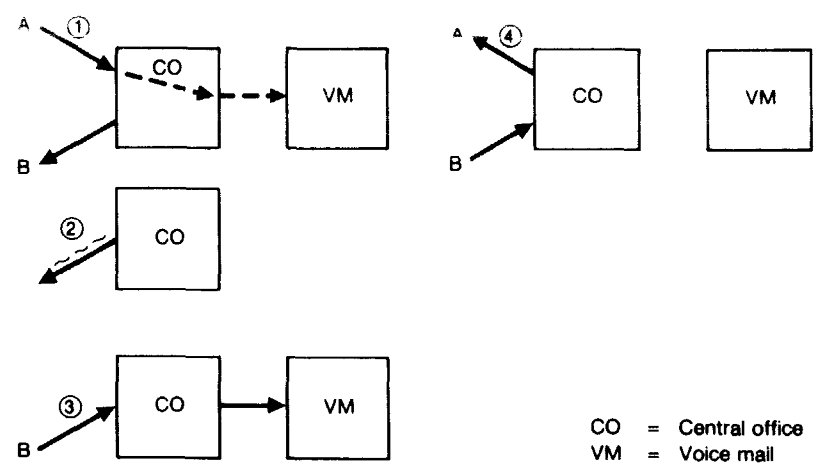


Fig. 10—Block diagram of voice mail calls

In the next step (panel 3) B dials a password plus a short code to obtain his message. The central office interprets this request code and passes it to the voice mail system, which replays the message. As shown in the figure, B retrieves the message using his regular telephone. But he could as well call from any other telephone to hear his message.

Finally (panel 4), B returns the call to A, either by making a regular call, or if B's number has been automatically recorded, by entering a call-back code that is translated by the central office into A's number.[3]

Figure 11 shows, in block diagram form, the equipment required for this service at both the central office and the voice mail provider. Calls flow to and from the voice mail machine over regular voice telephone lines. That machine consists of a digital computer and its software, a hard-disk system for digital storage of announcements and messages, and line cards for terminating the telephone lines. In addition, the voice mail machine is connected to the central office through data ports to a data line, which carries signaling and control information for handling each call. The number of incoming messages that can be processed at one time is limited by the number of voice lines.

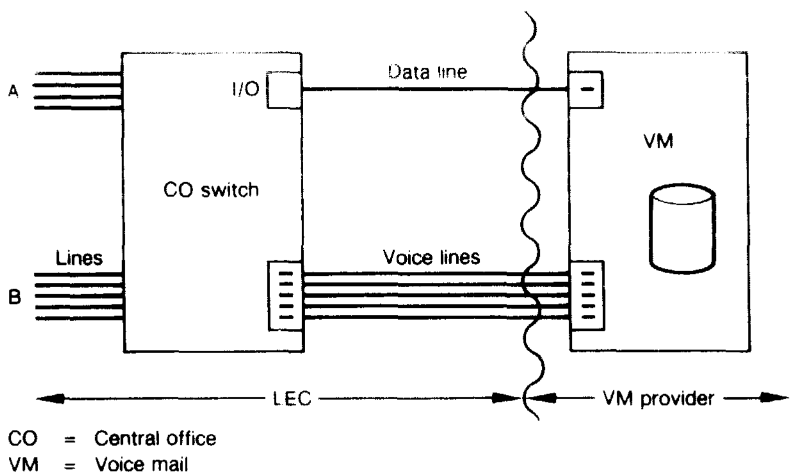


Fig. 11—Central office and voice mail equipment

[3]A particular call may not follow all of these steps. For example, a message might be complete in itself and require no follow-up call.

A voice mail provider's investment in a single machine is on the order of $100,000 or more, and to be viable it must serve hundreds of subscriber lines. To expand the potential market beyond a single central office, foreign-exchange lines can be used to connect the machine directly to more distant central offices.

Some providers are considering providing voice mail using large mainframe computers and high-capacity disk systems from a few central locations. The machines would be linked by trunks to a traffic concentration point that serves a group of local switches. This design would aim to achieve economies of large-scale processors and have the capability of adding information gateway and database services to the voice mail offering.

Incremental LEC Resources

To support voice mail service on subscribers' lines, the local exchange carrier incurs additional costs at the central office. Access lines that connect to the voice mail machine require much the same line termination and line card investment at the local switch as do access lines for individual subscribers. Additional termination equipment is required for the data port and a low-speed private data line to the voice mail machine. Each voice-mail line also requires some memory for translation and feature codes.

Use of the voice mail service during peak hours affects the call processor resources needed in the local switch. The incremental costs of greater (or fewer) busy-hour minutes of calling resulting from the voice mail system will be measured by the change in minutes times the average incremental cost per busy-hour CCS. In addition, extra processing is required to activate the message-waiting indicator and to handle message-retrieval and message-reply calls from the voice mail subscriber.

The local exchange carrier may need to update the software for the central office switch to support the provisioning of network components required by the voice mail provider.

If the LEC itself supplies voice mail service (and perhaps other enhanced services), it incurs some added administrative costs of complying with the regulatory requirements for separating its enhanced services and its regulated local exchange services. These costs, however, are attributable to the LEC's voice mail business (and other enhanced services); they are not incurred in supplying service elements to other vendors.

AIC for the LEC's Service Elements

Average incremental cost estimates for the major LEC service elements required for voice mail can be constructed by using the AIC estimates for basic access and usage, augmented by estimates for selected additional components. These components can then be combined to estimate the incremental cost of individual LEC service elements or features, based on the typical incidence of busy-hour usage.

1. Capital cost components

Voice access line. Average incremental cost of access consists of (1) the AIC for local loop access plus (2) the AIC of termination and access at the local switch. For voice mail providers located remotely, the local loop AIC estimate may be used, based on the distance of the provider from the central office. Some voice mail providers will, however, locate in close proximity to the central office, in which case a separate study will be needed of the major cost elements of providing "virtual co-location" lines to a provider. The incremental cost of voice line termination and access at the local switch can be estimated by using the AIC estimate for basic access.

Call distribution feature. The voice mail provider will typically combine a number of voice access lines with a uniform call distribution or hunt group feature in order to concentrate access from a larger number of voice mail subscribers onto a limited number of lines between the central office and the voice mail machine. An AIC estimate for the call distribution feature would either be obtained from a study of AIC components of centrex features or developed separately for this application.

Data access line. The AIC of supplying a data access line can use estimates developed for private line service, including the appropriate terminating electronics (plug-ins, modems).

Busy-hour processing. Use AIC estimates for the incremental cost per busy-hour CCS in the local switch. Estimate additional incremental cost components for specific services, such as message-waiting indication and abbreviated-dialing, based on switch vendor information or SCIS model data on the processor resources required per service event.

Develop estimates of the busy-hour occurrence of service events—message-waiting indication, abbreviated dialing retrieval of messages, and call forwarding. For each type of event apply AIC estimates for the busy-hour processing required.

2. Expense components

Maintenance. Apply AIC estimates for local loop maintenance per mile to the voice and data access lines. Apply AIC estimates for switch maintenance per access line and per busy-hour CCS.

Nonrecurring expenses. Develop estimates of provisioning expenses from average service-order times to establish voice and data line service with optional features and to open a new multiline account. Apply broad-gauge hourly labor costs, excluding overhead loadings.

Estimate the incremental cost per switch for the additional software required at the LEC switch to support voice mail service network components.

Billing. Estimate incremental billing expense for billing the voice mail vendor for the use of network components, using estimates of AIC per month and AIC per line for summary billing. If the LEC also provides customer billing and account collection service for the voice mail provider, estimate incremental costs for this service element from the AIC per line for summary billing and develop a factor for account collection and disbursement from billing activity studies.

LEC Pricing of Basic Service Elements

Local exchange companies are expected to offer the essential access and switching services required by a voice mail provider as Basic Service Elements (BSEs) under an Open Network Architecture (ONA) tariff. Enhanced service providers, whether independent firms or a LEC entity, would purchase services under these terms. Until ONA plans are fully implemented, however, voice mail providers will purchase network components under equal terms and conditions under existing tariffs. Large voice mail customers may, in addition, have the option of purchasing the service elements under individual contracts.

The primary service elements required for basic voice mail service are voice access line, data access line, forwarded-call information, message-waiting indicator, and call forwarding (when busy, or don't answer).

In a market trial at several locations Pacific Bell has experimented with the rates shown in Table 17. The rate for each service element consists of a nonrecurring charge plus a monthly rate.

Vendor Pricing of Voice Mail Services

Telephone subscribers purchase local telephone service from the LEC and voice mail services from the voice mail provider. Billing and collection for the voice mail service may be performed by the LEC, as

Table 17

MARKET TRIAL RATES FOR VOICE MAIL SERVICE ELEMENTS

Element	Nonrecurring	Per month
Per switch		
Forwarded-call information	$3500	$450
Activate message-waiting indicator	$2500	$250
Per line		
Message-waiting indicator (tone)	$9	$.50
Call-forwarding	$9	$1.20–$1.75
Voice access line (sgl. line bus.)	$70	$8.35 + usage
Data access line	$700	$28 + $2/mile

NOTE: Rates vary +/ 50 percent at different trial sites.

an additional service element, or billed directly by the voice mail provider.

Voice mail vendors' rates for basic call answering service and voice mailbox service in early trials are shown in Table 18. In addition to these rates, in several cases business customers with a large number of telephone lines will purchase bulk capacity from the voice mail provider—a number of ports and message storage—which they can themselves configure to provide voice mailboxes at a grade of service determined by the capacity and peak calling rates.

Table 18

RATES FOR VOICE MAIL SERVICES

Service	Nonrecurring	Per month
Call answering service		
Residence	$7/order	$6/line/month
Small business	$15/order	$12/line/month
Centrex	$15/order	$10/line/month + $.10/minute
Directly-dialed, nonintegrated voice mailbox	$15	$20/box/month

SIGNALING SYSTEM 7 AND 800-DATABASE SERVICES

The Signaling Network

The local exchange network modeled earlier is based on the dominant single-network technology in use in California today. Both subscriber calls and the signaling and control information they require are transported on the same facilities and use the same switches.

In the long-distance interexchange networks this technology has largely been replaced by two closely coupled networks—the message transport network, and a separate interoffice (digital) data network that carries all signaling and network control data in a common channel. Separating the signaling, which is inherently digital, from the message traffic itself has resulted in faster call setups, reduced the capacity required for the same volume of busy-hour traffic, and made possible the development of new services.

Local exchange carriers are in the process of introducing this technology into the local network using the standardized Signaling System #7 (SS7) protocol. The initial benefits from the new technology are being realized for tandem-switched calls. But with additional equipment and software, this technology also provides the opportunity to make a wide variety of new services available. These services are produced by specialized computer processing that is supplied either within the local exchange network or by enhanced service providers connected to it.

New Services

800-Database service makes it possible for a business subscriber to have a single "toll-free" telephone number which his customers may call, regardless of their location. The incoming calls can be routed to different telephone numbers or locations in the business, according to time of day or day of the week.

Alternate Billing Service enables an interexchange carrier to supplement its direct-dial long-distance service with telephone calling-card service, billing to a third party, and collect calls.

A third group of features, collectively termed Custom Local Area Signaling Services (CLASS), are based on transmitting the telephone number of the caller to the called telephone before ringing begins. Using this "caller ID" information, the subscriber receiving calls can "program" his telephone line to select certain calls that should be automatically accepted, be rejected, or be forwarded to another number. Also, the user can be notified that a second call is waiting and the calling number can be displayed at a suitably equipped telephone instrument. Other features enable subscribers to automatically re-dial a number that is busy when it hangs up, and to call back to the last calling party.

The SS7 technology may allow larger business subscribers to establish their own "virtual networks" linking disparate locations. Calls will be routed according to configuration information specified by the subscriber and stored in a network database.

Stylized Technology

To understand the elements of the SS7 technology required for new features, it is helpful to first follow the handling of an interoffice POTS call that passes through a common-channel signaling network.

Figure 12 represents in simplified diagrammatic form the path of a call from one subscriber, A, to another subscriber, B, in a different local office.

At A's central office, the local switch sends a data message containing both A's and B's telephone numbers over the data network, shown by dashed lines. This message is passed through the signaling network to B's central office. There the switch determines whether B's line is

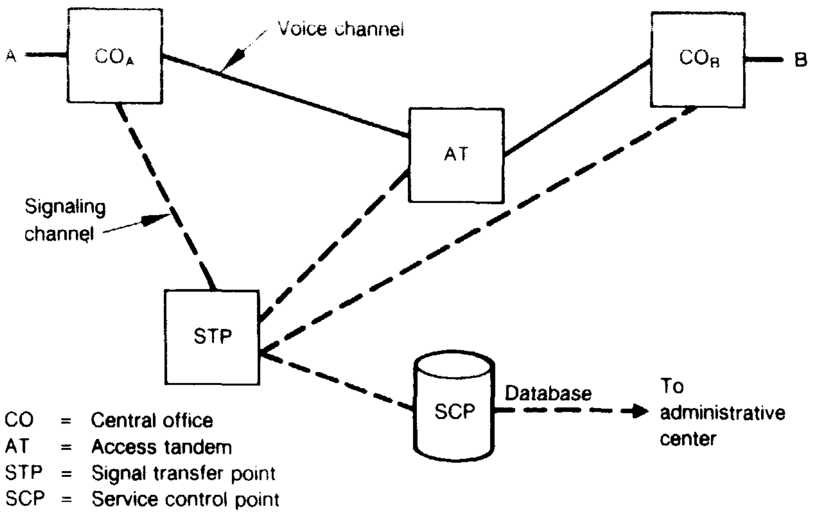


Fig. 12—Block diagram of common-channel signaling

busy. If it is, it returns a "line-busy" data message; A's office receives the message and plays a busy-tone to caller A.

If the line is not busy, the switch in B's central office rings B's telephone. When B answers, the switch sends an "answered" data message back. Only then does the network establish a connection for the voice traffic between office A and office B, shown by solid lines. Finally, when the conversation is finished, the two switches send "hang-up" messages to the signaling network, which then removes the voice connection.

The common-channel network itself consists of 56 or 64 Kbps digital links that connect the central office switches to special packet switches called signal transfer points (STPs). Fewer than 10 pairs of STPs will be needed to serve most of California. Geographically separated STPs are linked in pairs to ensure a high degree of reliability; each has sufficient capacity to perform the tasks of the other, should one fail.

800-Database Service

The new features being developed to work with the SS7 network all function by intervening at some point in this signaling process to interpret, add, or change the data used in handling a basic POTS call. When subscriber A dials an "800" number, the additional step that is required is to convert this number into a regular "POTS-routeable" telephone number. Once it has been converted, the call can be handled in the usual fashion.

Conversion of 800 numbers involves looking up the dialed number in an online database, translating the number, and returning the translated number to the signaling network. The SS7 system is designed to allow such computer processing functions to be added to the basic signaling network. This is accomplished by attaching, as additional nodes in the network, service control points (SCPs) that can perform these feature-specific services. For 800-Database service the major equipment needed at an SCP is a minicomputer, high-capacity disk storage, and interfaces to the SS7 network. Some five or six SCPs should be sufficient to serve projected demand in California.

In addition to its primary function of looking up and translating 800 telephone numbers, the SCP computers can be programmed to extract statistics on use of the database, for example to provide an 800-Database business subscriber with information about the geographic distribution of callers. Supply of these features requires additional software, increased computer processing and greater disk storage capacity.

Incremental Costs

Construction of the backbone SS7 network connecting local exchanges will require major investments in the signal transfer point data switches, data links between local switches and the data switches, and additional hardware and software in the local switches. The new network will also require ongoing administrative and maintenance expenses. The carriers are deploying the signaling network in stages, beginning with a minimum number of STPs and their links to access tandem switches. Local switches will be equipped with SS7 signaling in stages, beginning with central offices that have a high degree of interoffice traffic in common.

SS7 will have some effect on the average incremental cost of local usage calculated in this study. Common-channel signaling via the new network will add new components of incremental costs. However, SS7 is also expected to reduce the costs of local switching and interoffice transport. When SS7 has been deployed to the point that it can handle a high proportion of local interoffice calling, most of the interoffice call processing functions now performed in the local switch will then be performed in the signaling network. In addition, the interoffice traffic that currently consists of call signaling will be transported over the data network. These advances will increase the effective call-processing capacity of both the local switches and the effective capacity of interoffice trunks and thus reduce the average incremental cost of those components of the local exchange. At the present stage of development, the net effect of SS7 on the average incremental cost of local usage is not yet known.

Once the backbone signaling network is in place, the costs of providing a database service are of several types:

- Investment in the SCPs that provide the database, plus its links to the signal transfer points in the network, and any reinforcements of the network required to handle the additional data messages.
- Control software must be added to the access tandem and central office switches to enable them to send query messages to the SCPs and receive translated numbers back.
- Administration, testing, and maintenance require data links and ongoing services from centralized SS7 administrative facilities.

All of these costs would be outlays incurred in first offering the 800-Database service. Once an SS7 network and 800-Database service

is operating, the average incremental cost of additional units of service would be the average cost, per unit of effective capacity, of expanding capacity.

Most of the major components of the 800-Database system—the service control points and the data links—are investment lumps that would be expanded to serve additional demand. Maintenance and administrative services from the national service center would presumably also expand with added equipment. Thus, the average incremental cost of 800-Database service is likely to be similar to the initial costs of constructing the database system, when calculated per unit of effective capacity.[4]

Although the other new services that are being developed using the SS7 network have many similar elements, the incremental costs of new features will depend greatly on the technical characteristics. The 800-Database service can be offered by installing additional software primarily at the access tandem switches. In contrast, the CLASS features will require extending the SS7 network to each central office, with significant investment in equipment as well as software upgrade expenses.

[4]If other SS7 services are also supplied by the same SCP, the incremental cost of one service would be calculated by increasing the output of that service while holding other outputs constant.

IX. CONCLUSION

We have constructed a small-scale engineering-economic model of the local exchange company's local loop, local switch, and interoffice transport facilities. Using data representative of California conditions we have evaluated the parameters of the model, focusing on the average incremental costs of access and local usage in an existing local telephone network.

Our estimates are intended to measure the extra costs of providing additional access and greater local usage in an existing local telephone network. These costs include the annual costs of increased investment to expand capacity and the recurring expenses for maintenance, billing, and accounting.

We have excluded the startup and overhead costs of the local exchange firm—major fixed costs that must be incurred once and recovered in the rates of a self-sufficient company. Table 19 summarizes the major cost elements that have been included and excluded in the incremental cost calculations in this report.

We have estimated the range of average incremental costs for typical community conditions in California, assuming that increases in demand will be met with current analog local loops, digital switching, and interoffice fiberoptic transmission technologies.

Incremental costs of access vary widely, because of differences in the length of average loops and the rates of growth across communities. In contrast, incremental costs of usage are quite similar in different communities, with variations resulting from differences in switching equipment and the amount of interoffice calling.

Residential and single-line business subscribers in the same community have broadly similar incremental costs per line. Residential subscribers tend to have higher access but lower usage incremental costs per line.

The local exchange network has substantial fixed costs that must be incurred to provide initial service to a neighborhood, switch calls, and supply connections to other offices. Per line, these costs are commensurate with the incremental costs of access and are dominated by the investment in the final distribution portion of the local loop.

Access and usage of the network for local calls are plain old telephone service—the mainstay of the local exchange business. But access and local usage are also essential to the production of most other local and long-distance telephone services.

Table 19

COST ELEMENTS INCLUDED AND EXCLUDED IN INCREMENTAL COSTS ESTIMATED IN THIS STUDY

Category	Included	Excluded
Local loop	Feeder cable, installation Feeder structures (med. and high-growth areas)	Distribution plant Land, buildings, right-of-way
Wire center and switch	Line cards Switch matrix Trunk units Central processor (med. and high-growth areas)	Main distribution frame Switch frame Right-to-use software fees
Interoffice transport	Multiplexers	Fiberoptic cable Ducts, repeaters Crossconnects Lightwave interconnect unit
Expenses	Cost of capital Income taxes Capital replacement Maintenance Billing and accounting	Marketing Operator and directory services Property taxes General administration Legal and regulatory affairs Moves and rearrangements

Telephone calls between subscribers not located in the same community require additional network switching. At busy hours the incremental costs of these calls are some two to four times the average incremental costs of local calls.

Our incremental cost methods can serve as the foundation for assessing the incremental costs of a wide variety of telecommunications services. We have examined the salient characteristics of centrex, private line, voice mail, and common-channel signaling services and identified functional components and sources of data that can be used to extend the model developed in this study.

Appendix A

SOURCES OF DATA

GTE and Pacific Bell made a wide range of company data available for this study. We have drawn on engineers' planning tools, design documents and computer programs, company studies of cost components, special studies and filings prepared for the California Public Utilities Commission (CPUC), and company investment and expense records.

We have also had access to technical, pricing, and cost information provided by manufacturers of central office switches.

In this appendix we indicate the major data sources that were consulted in the course of the project.

Loop length

- 1986 CPUC Notice of Inquiry
- Operating company sampling studies of central offices and wire centers
- Operating company outside plant accounts

Cable cost

- Operating company broad-gauge cost studies
- Operating company outside plant average unit cable investment

Cable utilization

- Operating company 1986 outside plant utilization studies prepared for CPUC

Structural investment factors

- Operating company construction and plant-in-service accounts